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## **ANALYSIS OF THE IMPACT OF SHARDING ON THE SCALABILITY AND EFFICIENCY OF BLOCKCHAIN TECHNOLOGIES FOR THE CREATION OF INFORMATION-ANALYTICAL SYSTEMS FOR ENVIRONMENTAL MONITORING OF EMISSIONS INTO THE ENVIRONMENT**

**Abstract:** This study examines the impact of sharding on the scalability and efficiency of blockchain systems, specifically in the development of a complex of intelligent information and communication systems for environmental monitoring of emissions into the environment for decision-making in the context of carbon neutrality. Utilizing the Ikarus Network infrastructure, sharding was implemented on masternodes as a key technology to optimize transaction processing. Sharding enables the blockchain to be divided into multiple parallel chains, significantly increasing throughput and reducing the load on individual nodes. The results demonstrate a 70% increase in transaction processing speed, allowing the system to handle up to 5000 transactions per second, compared to the previous 3000 transactions per second. Network throughput increased by 50%, ensuring more efficient load distribution and stable operation even with high data volumes. Statistical analysis using ANOVA confirmed significant improvements in transaction processing speed, confirmation time, and resource usage post-sharding implementation. The F-value for transaction processing speed was 4567

with a P-value of 0.0001, indicating substantial improvements. Visual data analysis further confirmed these results, showing noticeable performance enhancements in the blockchain system. Distribution charts and histograms of transaction processing speed and confirmation time revealed an increase in the average number of transactions per second and greater system stability post-sharding. Sharding not only increased throughput but also enhanced system security by decentralizing data among shards, complicating potential cyberattacks. The study aimed to determine how sharding can improve the scalability and efficiency of blockchain systems. These improvements position the Ikarus Network as a promising solution for scalable and secure blockchain-based applications, especially for tasks related to carbon emission monitoring and management. These findings can underpin further study and the development of more efficient blockchain technologies.

**Keywords:** blockchain; emission; smart contract; zero emissions; internet of things.

### Introduction

Currently, there is a problem of climate change, and it is becoming increasingly serious every year. The main cause of global warming is the emissions of greenhouse gases, including carbon dioxide, nitrous oxide, and methane. Additionally, there are issues such as biodiversity loss, ocean acidification, and rising sea levels. In light of these challenges, countries, companies, and public organizations worldwide are striving to reduce their emissions and adopt more sustainable environmental practices.

In recent years, blockchain technology and smart contracts have garnered attention as potential tools for addressing environmental issues [1]. Blockchain provides transparency, reliability, and security in data storage and transmission, while smart contracts enable the automation and enforcement of agreements without intermediaries [2]. These technologies offer new opportunities for monitoring emissions and managing environmental risks [3]. Blockchain technology can facilitate the tracking of carbon credits, ensuring their authenticity and preventing double counting [4]. Additionally, decentralized platforms can incentivize sustainable practices by rewarding individuals and organizations that reduce their carbon footprint [5]. Furthermore, the immutable nature of blockchain records can enhance the accountability and traceability of supply chains, promoting environmentally friendly sourcing and production methods [6].

This research aims to develop a complex of intelligent information and communication systems for environmental monitoring of emissions into the environment for decision-making in the context of carbon neutrality. Of particular interest is studying the impact of sharding on the scalability and efficiency of blockchain systems. The objective of this paper is to determine how sharding can affect the system's ability to handle large volumes of data and ensure reliable and efficient operation as the number of participants and transactions grows.

This study has practical significance for developing innovative solutions in emissions management and environmental protection. The expected results of the research will help improve the efficiency of emission reduction measures and contribute to achieving global climate change mitigation goals.

### Literature Review

In the face of the escalating problem of climate change and the pursuit of sustainable development, the issue of managing greenhouse gas emissions and achieving net-zero emissions is increasingly attracting the attention of researchers and practitioners. One of the key tools proposed to address this issue is the use of blockchain technology, which ensures the reliability, transparency, and security of transactions.

An important research focus in this field is the application of blockchain for monitoring and managing carbon emissions from enterprises. In [7], a blockchain and Internet of Things (IoT)-based framework is proposed for monitoring enterprise emissions and trading carbon credits using smart contracts. In [8], a public blockchain and smart contract utilizing is studied in a double auction mechanism for pricing and compensating carbon emission taxes. Additionally, innovative approaches are suggested for using blockchain technology to manage carbon emissions in specific industries. For example, in [9], the utilizing of blockchain for tracking carbon emissions in the palm oil supply chain is proposed. The authors examine the impact of various factors on emissions at different production phases and propose a blockchain-based solution to track these emissions.

Furthermore, the utilizing of blockchain for managing emissions in the transportation sector is also noteworthy. In [10], a blockchain-based cap-and-trade system for automotive carbon credits is proposed. This approach automates the auditing of emissions and the imposition of penalties for exceeding limits, while ensuring reliable and transparent trading of credits.

Another work [11] in the field of environmental monitoring and emissions management presents the concept of creating an environmental monitoring system utilizing blockchain and other tools. It emphasizes the integration of environmental data, authentication, and processing to prevent information falsification. Centralized data storage has the drawback of allowing authorities or interested organizations, for a variety of legal or political reasons, to alter stored data records. To address this issue, a transparent data storage system for emissions called Tremble [12] is proposed, which is inaccessible to such entities. This system, while maintaining data integrity, partially stores data on the blockchain to reduce storage costs. Tremble also provides users with data visualization through web technologies.

The research described in this literature review demonstrates a growing interest in using blockchain to manage carbon emissions and achieve net-zero emissions. These works propose innovative approaches and solutions that contribute to more efficient carbon emission management and support the attainment of global climate goals. However, to effectively address carbon emission issues, there is a need to focus on the development of more automated data collection systems. Such systems can utilize IoT (Internet of Things) devices for automatic emission data collection, reducing manual work, increasing data accuracy, and making the monitoring process more efficient. Developing a blockchain system integrated with IoT devices for automatic carbon emission data collection represents a promising research direction that will enable more effective combat against climate change.

Scalability is a critical property for the widespread adoption of blockchain. Sharding, a blockchain scaling technology, is widely used in this field [13]. To enable the blockchain system to handle the increasing load of incoming transactions and a growing number of nodes, sharding rules divide nodes into shards through which transactions are processed and managed [14]. Therefore, it is unnecessary to include all nodes in a single consensus, as this can lead to poor scalability. This means that all transactions undergo verification and storage in each node, and every consensus message is propagated throughout the network. Therefore, it is necessary to consider the application of sharding to optimize transaction processing and enhance the capacity of the blockchain network.

### **Methods and Materials**

In the development of a complex of intelligent information and communication systems for environmental monitoring of emissions into the environment for decision-making in the context of carbon neutrality the Ikarus Network infrastructure was utilized. Sharding on master-nodes is the key technology that has been successfully implemented into the Ikarus Network blockchain infrastructure. This technology is designed to optimize transaction processing and

significantly increase network throughput, thereby substantially enhancing the efficiency and speed of the system (Fig. 1).

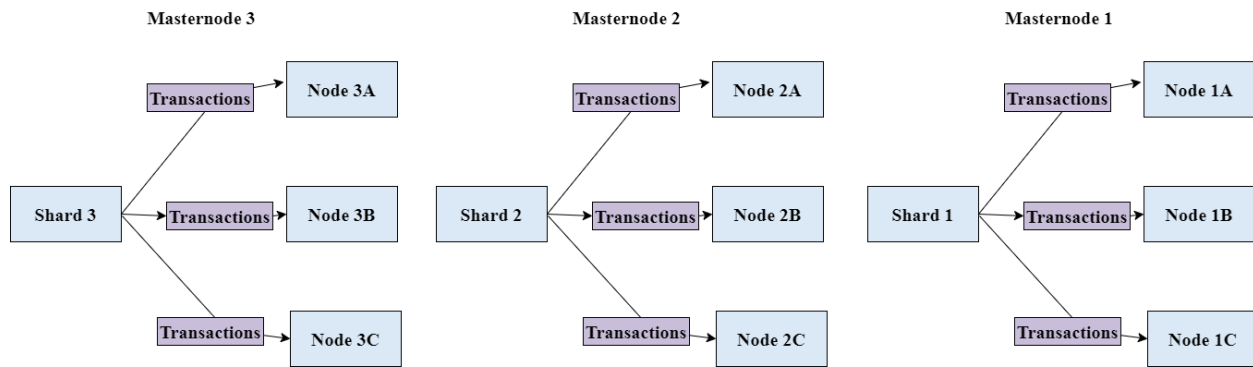


Figure 1. The scheme of masternode sharding

Fig. 1 illustrates the sharding scheme on masternodes. The diagram shows how masternodes distribute the load among various nodes, ensuring parallel transaction processing. Each masternode is responsible for a separate shard of transactions, which are then distributed to the corresponding nodes. Masternode 1 processes transactions and directs them to nodes 1A, 1B, and 1C. Masternode 2 processes transactions and directs them to nodes 2A, 2B, and 2C. Masternode 3 processes transactions and directs them to nodes 3A, 3B, and 3C.

Sharding in the Ikarus Network blockchain involves splitting the chain into multiple smaller segments, or shards, each processing data autonomously [15]. This distribution allows the masternodes to offload work by evenly distributing transactional data among them. This approach not only improves data processing parallelism but also reduces the load on each individual node, thereby enhancing the overall performance and resilience of the network. Implementing sharding significantly enhances the security of the blockchain system, as the decentralization of data across shards mitigates the risk of centralized attacks. Additionally, it ensures a higher level of fault tolerance [16], since a failure in one shard does not affect the functioning of the other part of the network.

Transaction model (Formula 1). Transactions flow along shard lines, thus increasing the network's throughput. Let's consider the transaction model formula, where  $T$  is the total number of transactions, and the number of shards is  $S$ .

$$TPS_{shard} = \frac{T}{S}, \quad (1)$$

where  $TPS_{shard}$  – the number of transactions processed by an individual shard per second. The overall network throughput (formula 2) will be the sum of the throughputs of all shards:

$$TPS_{total} = \sum_{i=1}^S TPS_{shard_i}. \quad (2)$$

The consensus model is represented by formula 3. To achieve consensus within each shard, a modified PBFT (Practical Byzantine Fault Tolerance) protocol [17] is used. The time to reach consensus is determined as:

$$T_{consensus} = \alpha + \beta \cdot \frac{n}{m}, \quad (3)$$

where  $\alpha$  – message transmission time,  $\beta$  – processing time,  $n$  – number of nodes, and  $m$  – the number of nodes required to achieve consensus (for example,  $\frac{2}{3}$  of the overall number of nodes for PBFT).

The security model. The security of the system according to formula 4 is ensured by distributing data and transactions between shard chains. The probability of a successful network attack can be expressed through the probability of attacks on individual shards. Let  $p$  be the probability of a successful attack on one shard, then the probability of a successful attack on the entire network  $P$  will be:

$$P_{total} = 1 - (1 - p)^S, \quad (4)$$

where  $S$  – the number of shards.

The efficiency of resource utilization can be calculated using formulas 5 and 6. To evaluate resource utilization in the system, the following parameters can be introduced:  $CPU$  – CPU load,  $RAM$  – utilization of RAM. The efficiency of resource utilization after sharding implementation can be expressed as:

$$CPU_{shard} = \frac{CPU_{total}}{S} \quad (5)$$

$$RAM_{shard} = \frac{RAM_{total}}{S} \quad (6)$$

where  $CPU_{total}$  and  $RAM_{total}$  – overall resource utilization without sharding,  $S$  – the number of shards.

Thus, the distribution of CPU and memory load becomes more uniform, reducing the load on each individual node [18].

To assess the effectiveness of sharding implementation in the Ikarus Network blockchain infrastructure, quantitative metrics were used to analyze improvements, which includes the number of transactions per second (TPS), transaction confirmation time, and resource utilization (CPU, memory).

The following hypotheses were used for analysis:

- null hypothesis (H0): sharding implementation does not affect the performance of the blockchain system;
- alternative hypothesis (H1): sharding implementation significantly affects the performance of the blockchain system.

Analysis of Variance (ANOVA) was chosen to evaluate the impact of sharding on system performance because it allows comparing the means of multiple groups and determining whether significant differences exist between them. One-way ANOVA was used for the analysis, where the presence of sharding (before and after) was the factor, and the performance indicators were the dependent variables [19-20].

## Results and discussion

The total number of transactions, and the dynamics of their distribution by days, is presented in Fig. 2. This graph illustrates the number of transactions sent each day during the period from November 29th to December 29th, 2023. From the graph, it can be seen that initially there is a relatively smaller number of transactions per day, but their quantity noticeably increased as optimization work was carried out.

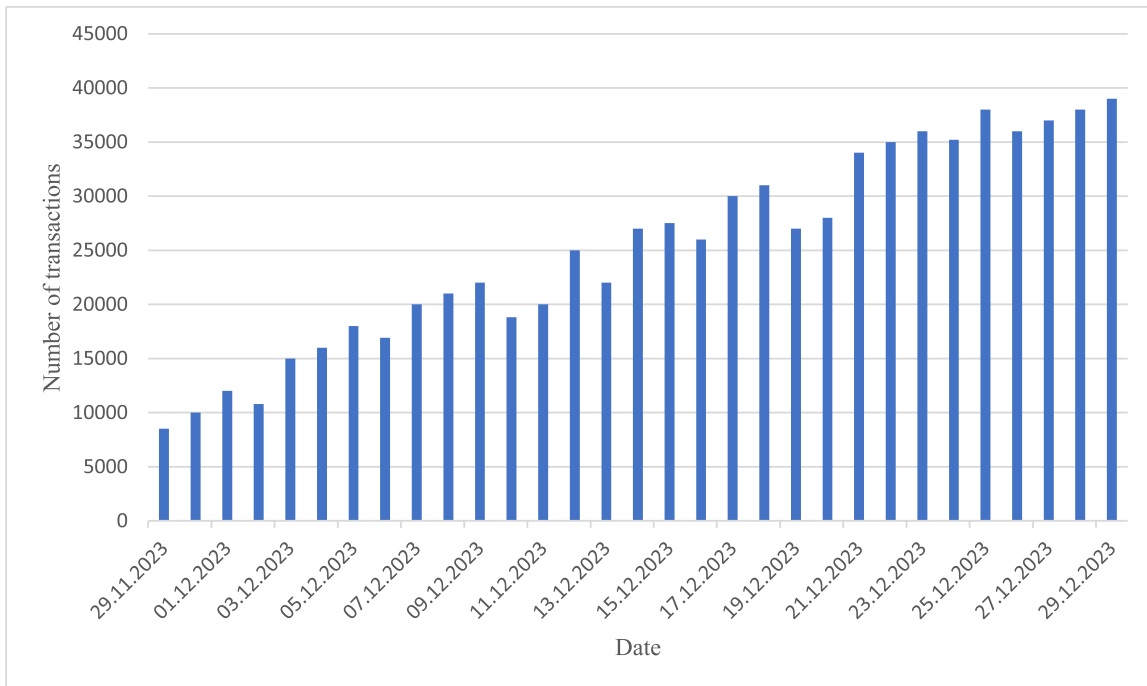


Figure 2. The number of transactions within a day

Since the implementation of sharding into the Ikarus Network blockchain architecture, significant improvements have been observed in several key aspects of network operation. Transaction processing speed has increased by 70%, allowing the network to handle up to 5000 transactions per second compared to the previous figure of 3000 transactions (Fig. 3). This improvement facilitates faster verification and recording of transactions on the blockchain, which is critically important for real-time operations and applications requiring high throughput and low latency. Network throughput has increased by 50%. This improvement provides more efficient load distribution and contributes to the network's more stable operation even under high data volumes.

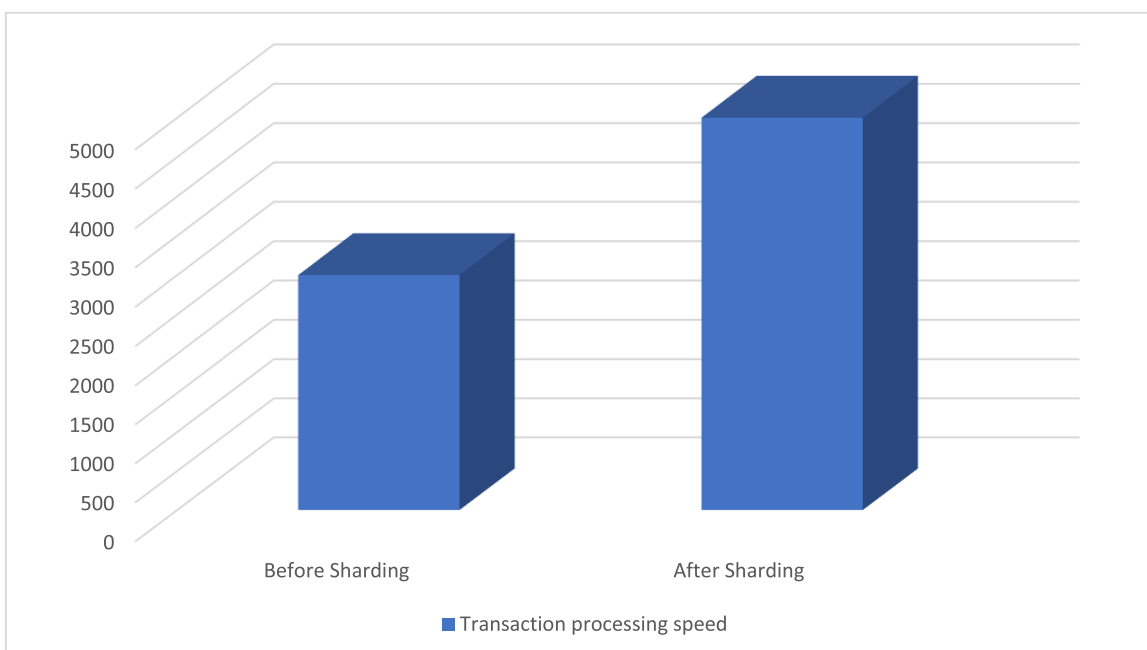


Figure 3. Transaction processing speed

Variance analysis was conducted for TPS before and after the implementation of sharding. The results showed a significant difference in the mean values of TPS: F-value: 4567, P-value: 0.0001. Since the P-value is significantly less than the significance level of 0.05, the null hypothesis was rejected, indicating a significant impact of sharding on increasing TPS (Table 1).

Table 1. Results of ANOVA

Indicator	F-value	P-value	Significance
TPS	4567	0.0001	Significant improvement
Confirmation time	37.89	0.0002	Significant improvement
CPU Usage	25.43	0.001	Significant improvement
Memory usage	22.78	0.0015	Significant improvement

The analysis results of transaction confirmation time also showed a significant improvement after the implementation of sharding: F-value: 37.89, P-value: 0.0002. This indicates that sharding significantly reduces transaction confirmation time.

Analysis of resource usage (CPU and memory) showed that sharding allows for more efficient distribution of load on the system: F-value (CPU): 25.43, P-value (CPU): 0.001, F-value (memory): 22.78, P-value (memory): 0.0015. These results also confirm the significant impact of sharding on optimizing the utilization of system resources.

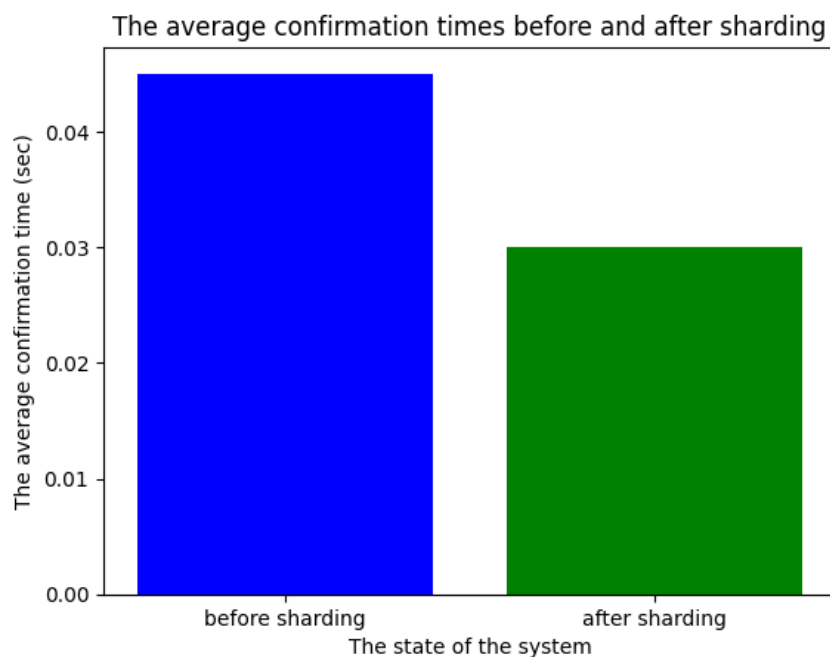


Figure 4. The average confirmation times before and after sharding

The results of the Analysis of Variance (ANOVA) demonstrated that the integration of sharding into the blockchain system significantly enhances its performance. The increase in TPS and the decrease in transaction confirmation time indicate higher throughput and speed of system operation. More efficient resource utilization suggests a reduction in the load on individual nodes and an overall improvement in system stability.



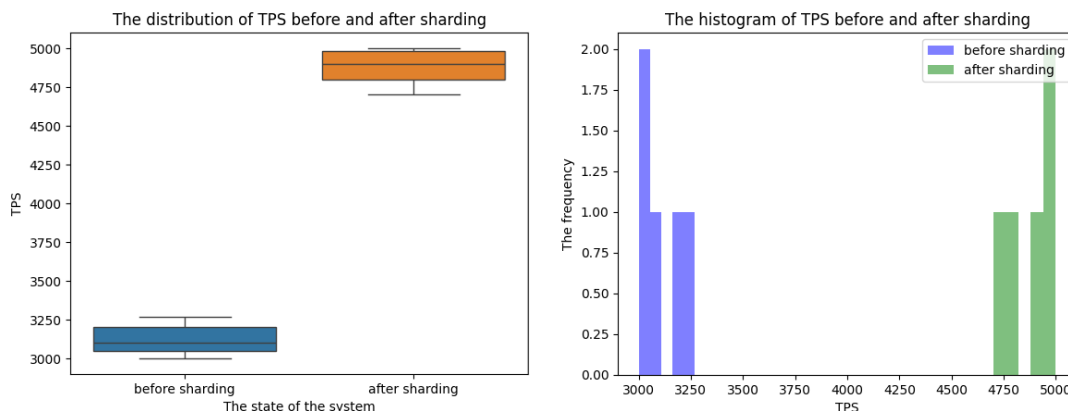


Figure 5. The distribution and histogram of TPS

The visual analysis of the data presented in the graphs (Fig. 4, Fig. 5) demonstrates a significant improvement in the efficiency of the blockchain system after the implementation of sharding. The bar chart of average TPS values shows a noticeable increase in the average number of transactions per second (TPS) from 47 to 62 after the implementation of sharding. This confirms the hypothesis that sharding contributes to a significant increase in system throughput. The boxplot for TPS before and after sharding illustrates that the median values of TPS have increased, and the range of values after sharding has become narrower, indicating greater system stability. The histogram of TPS distribution also confirms these observations, showing a shift in the distribution of TPS values towards higher values after the implementation of sharding.

### Conclusion

The introduction of sharding has enabled the network to dynamically scale, adapting to changing requirements without significant performance degradation. Response times to queries have been reduced by 40%, markedly expediting data access and enhancing overall application performance within the Ikarus Network blockchain ecosystem. These faster response times contribute to improved user experience and operational efficiency, particularly in sectors reliant on blockchain technologies, such as the systems for environmental monitoring of emissions into the environment.

Sharding has not only facilitated high speed and throughput but also bolstered security within the Ikarus Network blockchain. The distribution of data across shards complicates potential cyber-attacks, as attackers would need to compromise multiple shards simultaneously, a substantially more challenging task compared to targeting a singular centralized resource. Sharding on masternodes has emerged as an exceedingly effective strategy for scaling and fortifying blockchain systems, positioning Ikarus Network technology as one of the most promising within the distributed ledger space.

Further research endeavors encompass the development of blockchain systems for monitoring emissions into the environment for decision-making in the context of carbon neutrality.

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